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Dangers in Refining Radioactive Substances

The Reduction of Mine Air Temperatures

A Colorimetric Method for the Detection and Estimation of Small Amounts of Lead

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THE JOURNAL OF INDUSTRIAL HYGIENE

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DANGERS IN REFINING RADIOACTIVE SUBSTANCES*

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WHILE the dangers incident to the handling of high grade radioactive materials have long been known, recent investigations of cases of radium poisoning (1) (2), together with a number of unofficial reports, have drawn attention to the advisability of investigating more thoroughly the hazards involved in this occupation. Such an investigation has been in progress during the past three years in this laboratory, where the refining of commercial mesothorium through the final stages was being carried on. The purposes of this investigation were: first, to measure quantitatively the intensity of radiations remaining in the laboratory after precautions had been taken to reduce them to a minimum; second, to examine the workers for accumulated active material; and third, to keep a record of their physiologic and cytologic conditions. It is hoped that this and similar investigations may lead eventually to the removal of all dangers now involved in the handling of unsealed radioactive substances.

The refining operations were carried out by three students, each working from fifteen to thirty hours a week. They purified and fractionally crystallized the radioactive salts until the gamma ray activity per milligram measured under standard conditions was 60 to 150 per cent. of that of 1 mg. of pure radium (element). The amount of mesothorium ordinarily present in the crystallizing system was from 100 to 300 mg. The laboratory itself was well lighted and ventilated, and was provided with a good hood with forced draft.

Table 1 shows the decomposition products of radium and mesothorium and their genetic relation (3). The activity of commercial mesothorium is due to the presence of radium, mesothorium 1, and their transformation products in such proportions

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that from 10 to 20 per cent. of the gamma ray activity of the preparation one month after sealing is due to members of the radium series. Not with mesothorium 2; radium D and radiothorium, although slowly accumulating, are present in amounts which are small compared to their equilib-

TABLE 1.—DECOMPOSITION PRODUCTS OF RADIUM AND MESOTHORIUM

ELEMENT	HALF VALUE PERIOD	RADIATION
Radium Series		
Radium	1,590 yrs.	alpha
Radon	3.85 days	alpha
Radium A	3.0 min.	alpha
Radium B	26.8 min.	beta and gamma
Radium C[1]	19.5 min.	beta and hard gamma
Radium C′	10^{-6} sec.	alpha
Radium D	16.5 yrs.	(beta and gamma)
Radium E	5.0 days	beta
Radium F	136 days	alpha
Radium G (Lead)	.....	.....
Mesothorium Series		
Mesothorium 1	6.7 yrs.	.....
Mesothorium 2	6.2 hrs.	beta and hard gamma
Radiothorium	2.02 yrs.	alpha
Thorium X	3.64 days	alpha
Thoron	54.5 sec.	alpha
Thorium A	0.14 sec.	alpha
Thorium B	10.6 hrs.	beta and gamma
Thorium C[2]	60.0 min.	65% beta
Thorium C′	10^{-11} sec.	alpha
Thorium Lead	.....	.....
Thorium C	.....	35% alpha
Thorium C″	3.1 min.	hard gamma
Thorium Lead	.....	.....

[1] A branching of the radium series occurs here, 0.03% of the radium C atoms emitting alpha rays.

[2] A branching of the mesothorium series occurs here, 65% of the atoms of thorium C undergoing a beta ray change forming thorium C′, while the other branch claiming 35% of the atoms of thorium C emit alpha rays and form thorium C″, often designated as thorium D, which finally changes into thorium lead with the emission of the hardest gamma rays of radioactive origin.

all the transformation products are present in equilibrium amounts, radium being in equilibrium with its first four products, and mesothorium 1 rium amounts. The quantities of other products present depend on the age of the preparation. Alpha rays are emitted by ten members of these

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series, among them thorium C′, which furnishes the longest range alpha particles known. The gamma ray activity is due principally to mesothorium 2, but radium C and thorium C″ also contribute their gamma radiations, the most penetrating known. Beta rays are emitted by six products, principally radium B, radium C, and mesothorium 2. Two other products of these series, radon and thoron, are gases and may escape into the atmosphere, there to decay with the emission of alpha particles. The rate of decay of all these substances is independent of the physical state and their chemical combination.

During the process of refining mesothorium by fractional crystallization, danger from some of the foregoing radiations is decreased since the salts are kept either in solution or in contact with solution at all times. Under these conditions the alpha rays are completely stopped and the beta rays almost completely absorbed by the dishes, solvent, and air. With reasonable care, the contact of solutions with the skin or the entrance of active matter into the body through the mouth can be prevented. Thus the principal sources of danger ordinarily present are the gamma radiations and the radioactive gases in the atmosphere.

There are times, however, when the dehydrated salts must be handled. In this work it is always possible that small particles may be dusted into the air and breathed into the lungs. This danger was removed in our operations by using a good hood with forced draft, provided with a large piece of plate glass placed between the worker and the active material. As an extra precaution the worker wore an improvised gas mask, so arranged that the air inhaled passed first through several thicknesses of moist gauze.

In order to reduce the intensity of gamma radiation from high grade materials (and also of unabsorbed beta), thick lead shields and lead containers for the crystallizing dishes were provided. Protection against the small intensity of gamma radiation emitted from the large bulk of low grade materials was unnecessary—the more so since the intensity at all stages of the process was reduced by the removal of some of the substances emitting gamma rays. Mesothorium 2, the principal source, could not be removed conveniently, for a daily precipitation would have been necessary. Radium C and thorium C″, however, were effectively removed by the separation of their parent substances, radon and radiothorium. Radon, being a gas, escaped during the daily boiling of the solutions; and radiothorium, together with heavy metallic impurities, was removed by precipitation with hydrogen sulphide in ammoniacal solution as the first step in the refining process. Since metallic impurities do not interfere with the work of refining, this precipitation has been omitted in the past by commercial laboratories.

The two isotopic radioactive gases, radon and thoron, are continuously produced in the active solutions; they partially escape into the atmosphere, where they decay with emission of alpha particles and formation of solid active deposit on all exposed surfaces. If this deposit is formed on the lining of the lungs, active materials may find their way into the blood stream and to various parts of the

body, there to decay with emission of all types of radiation. Fortunately, the amount of radiothorium in the original crude materials, as well as of its product thorium X, parent of thoron, is ordinarily small compared to the equilibrium amount. The rate of production of thoron by thorium X is therefore correspondingly small and would become zero in the course of a month after removal of radiothorium, were it not for the slow re-formation of this substance by mesothorium. As a result, the rate of formation of thoron during the crystallizations is probably not over 5 per cent. of the equilibrium rate at any time. Since there was apparently no means of preventing contamination, with these gases, of the air breathed by the workers, quantitative measurements were made of the amounts of each present in the laboratory.

Several methods have been employed for the detection and estimation of radon in the atmosphere, whereas thoron seems to have been determined only relative to radon by means of an analysis of decay curves (4) (5). Methods used for the quantitative determination of radon include: (1) absorption on cocoanut charcoal (6); (2) condensation by liquid air (7); (3) direct measurement in a large ionization chamber (8); and (4) exposing a negatively charged wire to accumulate an active deposit whose activity is measured in an alpha ray electroscope (5). In this investigation the third method was used for determination of radon, while a "continuous flow" was used for determining thoron.

Determination of Radon

A sample of filtered air from the region in the laboratory thought to possess the greatest activity was introduced into an evacuated ionization chamber of a Lind type of electroscope and the activity was measured at the end of three hours. As soon as the readings had been taken, the gas in the chamber was blown out with a stream of dry, inactive air. By this method both the thoron and the radon in the air entered the chamber, but the thoron soon decayed, leaving a deposit whose activity was found to be negligible. The quantity of mesothorium present at the time of the measurements was about 150 mg. The constant of the electroscope used was 15×10^{-9} curies per division per second (9), and the volume of the ionization chamber 3 liters. The calculations were made as follows:

$$(\text{Net drift}) \times 15 \times 10^{-9} \times \frac{1000}{3} = \text{curies per cu. m.}$$

The results of measurements made on different days are:

Net Drift *div./sec.*	*Radon* *curies/cu.m.*
0.020	1.0×10^{-7}
0.096	4.8×10^{-7}
0.035	1.8×10^{-7}
0.077	3.9×10^{-7}

These values, which do not vary greatly from day to day, are assumed to represent the maximum amounts of radon present under the usual laboratory conditions, with the fan running continuously. Although several thousand times as large as the radon

content of ordinary atmosphere (5) (10), they are insignificant compared to the amounts of thoron determined, as described in the following section.

Determination of Thoron

Method.—Thoron could not be determined in the same manner as radon because of its rapid rate of decay—half value in 54.5 seconds. A possible method was suggested by the work of Cartledge (11) and of Helmick (12) on the quantitative measurement of thorium in monazite sand. Using apparatus similar to that which they describe, the following procedure was devised: The electroscope was calibrated in terms of thoron, by drawing a steady current of inactive air through a standard solution of thorianite (an old mineral in which thorium is in equilibrium with thorium X) and then through the electroscope chamber. The thoron passing into the electroscope was immediately in equilibrium with thorium A (half value period = 0.14 second), and it was necessary to wait only a few minutes for the drift of the leaf to become constant. Thereafter, active air from the laboratory was drawn through the same system, except that an inactive solution of the same density and chemical composition (except for the thorianite) was substituted for the standard thorianite solution. It was thought that from the observed activities in the two cases the number of curies of thoron per cubic meter of laboratory air could be calculated. It was found, however, that a fallacious assumption was necessary: that the fraction of the emanation escaping from the active standard solution into the stream of inactive air was equal to the fraction remaining in the stream of active air after it had passed through the inert solution. Consequently this method could not be justified for the quantitative measurement of thoron, though approximate results might be obtained.

A somewhat different procedure was finally adopted. The electroscope was calibrated in terms of radon by the usual emanation method, and the calibration constant in terms of thoron calculated in the manner to be described later (see page 123). In making the measurements, active laboratory air was drawn through the electroscope chamber at a known and constant rate, producing an observed net rate of discharge. From the calibration constant in terms of thoron the number of curies of thoron apparently present in the chamber during the measurement was calculated; and from other constants of the apparatus it was possible to calculate the number of curies of thoron per cubic meter of laboratory air (see page 126).

The details of the apparatus are shown in Figure 1. The pressure regulator maintained the pressure constant to within 0.05 mm., small fluctuations due to the bubbling of excess air through the cylinder being equalized by the large volume of air in the carboy. Obviously the apparatus consists merely of a device for insuring constant rate of flow and a means of drawing active air from the laboratory into the electroscope.

The rate of flow of the air was determined in the following manner: Instead of being drawn from the laboratory, air was drawn from an aspirator bottle inverted in a jar of water, the pressure inside the bottle

being maintained at one atmosphere by lowering it into the water as air was removed. The time was observed on a stop watch and the total volume of air was measured by the inflow of water into the aspirator bottle; in this way the rate of flow was determined to within 0.05 c.c. per second. The tip thus calibrated was used at the intake during all measurements. The opening of this tip was quite small, resulting in a slow rate of flow of 6 c.c. per second. This rate was made slow in order to prevent too rapid a discharge of the electroscope, for under these circumstances the potential on the electrode is less than the saturation potential, and recombination of the ions may occur. An example of this is found in Table 3, Series 1; for such cases the amounts reported are less than the actual amounts. Because such high activities were seldom measured, it was thought unnecessary to obtain slower rates of flow.

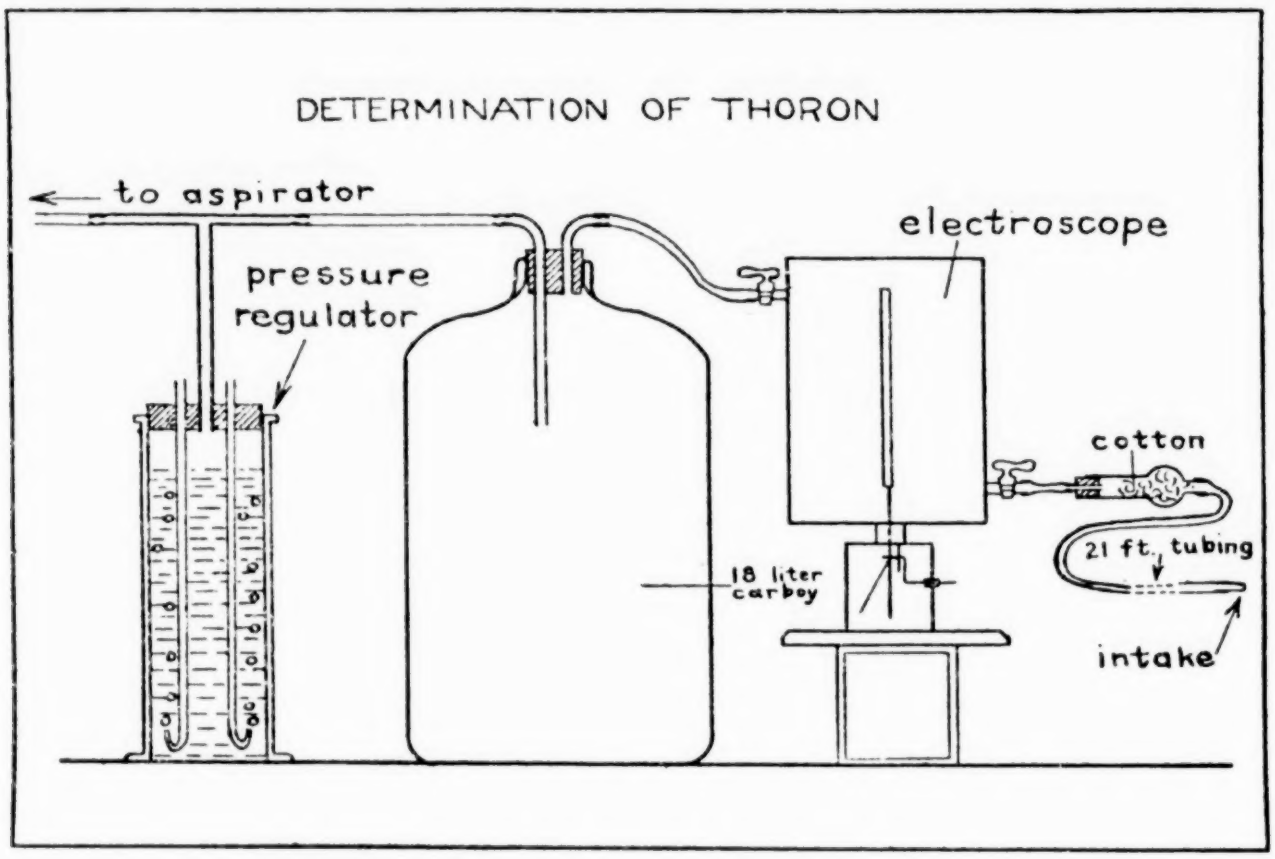

FIG. 1.—Apparatus used for the determination of thoron.

TABLE 2.—CONSTANTS OF ELECTROSCOPE USED IN DETERMINATION OF THORON[1]

Calibration constant of electroscope	27.5×10^{-9} curies/div./sec.
Electrostatic capacity (14)	14.8 cm.
Drop in potential per scale division	2.76 volts or 0.0092 e.s.u.
Ionization efficiency (14)	78%
Volume of electroscope chamber	2,840 c.c.
Volume of tubing and connections between intake and electroscope chamber	160 ± 0.5 c.c.

[1] The electroscope used was No. 5, described in the work of Randall (14).

The electroscope used was calibrated in terms of radon by the usual

emanation method, employing standard radium solutions prepared by Barker (13). The constants of the apparatus are found in Table 2.

Since the activity of a sample of laboratory air trapped in the electroscope decayed to half value in 54.5 seconds, the half life value for thoron, it was concluded that this was the active substance present. Furthermore, it was observed after a series of measurements that the natural drift was normal within the accuracy of our observations (3 to 5 per cent.). This indicated that thoron was not in equilibrium with thorium B and thorium C, but with thorium A only. Successive readings obtained with the apparatus shown in Figure 1 sometimes varied by as much as 50 per cent., owing to shifting convection currents in the room; in general, however, the agreement was much better, as is shown by the following figures, which represent the times required for the leaf to drift over 40 scale divisions with the intake at various positions in the laboratory:

Position		
1	2	3
sec.	*sec.*	*sec.*
77; 48	22.0	42; 34
64; 66	19.0	27; 36
62	18.5	36

In Table 3, the values for the net drift of the leaf are derived from the averages of sets of values such as the three listed above. Each series of measurements was made on a different day. After Series 2 of these measurements was made, the high grade salts were removed from the laboratory, and a new consignment containing approximately 100 mg. of activity was placed in solution. During the first four series the rate of flow of air through the apparatus was 5.75 $\pm$0.05 c.c. per second, and during the last two, 6 $\pm$0.05 c.c. per second.

Calculations.—The figures in the second column of Table 3 were obtained by subtracting the net rate of discharge due to the average amount of radon measured in the laboratory from the observed net rates of discharge, *i.e.*, a subtraction of about 0.01 division per second. To obtain the figures in the third column it was first necessary to convert the calibration in terms of curies of radon into curies of thoron by a comparison of the ionization currents produced by a curie of each gas under the respective conditions of their measurement. For this purpose a curie of thoron may be defined as the amount which furnishes the same number, 3.7×10^{10}, of alpha particles per second as 1 curie of radon; this is about 2.9×10^{12} atoms of thoron, as against 1.8×10^{16} atoms of radon (15) (16).

The ideal values of the ionization currents due to a curie of radon or thoron were calculated on the basis of the following assumptions: (1) that alpha rays from the gases exert their full ionizing effects; and (2) that only half of the alpha rays from solid products exert their full ionizing effects, provided they are sufficiently long lived to be deposited on the electrodes before decomposing. The following data on the ionizing power of single alpha particles from each of the substances involved were taken from the International Critical Tables (3):

TABLE 3.—MEASUREMENTS ON THORON

POSITION OF TIP	NET DRIFT OF LEAF DUE TO T_N *div./sec.*	CURIES OF T_N MEASURED	CURIES OF T_N PER CU.M.
Series 1			
Circulation in the room was at a minimum, the fan being off, and the windows and doors closed.			
1 ft. over central table	13.200	3.43×10^{-7}	6.28×10^{-3}
2 ft. over same spot	2.620	6.81×10^{-8}	1.25×10^{-3}
3 ft. over same spot	0.090	2.34×10^{-9}	4.28×10^{-5}
Series 2			
The fan had been running an hour or more before these measurements were taken. All the dishes were cold and many were covered with watch glasses.			
15 ft. from active material	0.020	5.20×10^{-10}	9.52×10^{-6}
3 ft. above central table	Activity attributed to radon.		
A few inches above same table	5.690	1.48×10^{-7}	2.71×10^{-3}
In flue of hood	2.000	5.20×10^{-8}	9.52×10^{-4}
Under central table 1 ft. from floor	0.378	9.83×10^{-9}	1.80×10^{-4}
Series 3			
This run is typical of operating conditions in the laboratory, with the fan running, windows open, and the dishes being heated in the process of crystallization.			
6 in. directly above head dish of new system	6.590	1.71×10^{-7}	3.13×10^{-3}
In front of head dish in same position as head of worker	1.050	2.73×10^{-8}	5.00×10^{-4}
Series 4			
The measurements of this series were made while the fan was not running, and the windows and doors were closed. The solutions in the dishes were cooling after being heated during the day.			
3 in. from floor, 12–15 ft. from mesothorium	0.187	4.86×10^{-9}	8.89×10^{-5}
5 ft. from floor over same spot	0.058	1.51×10^{-9}	2.76×10^{-5}
3 ft. above central table, on which was no active material	0.280	7.28×10^{-9}	1.33×10^{-4}
On table to left of hood, by 50 mg. active salts in large dishes	1.120	2.91×10^{-8}	5.33×10^{-4}
Series 5			
The ventilating fan in the hood had been running over two hours, but no windows were open, and there were no boiling or hot dishes.			
$2\frac{1}{2}$ ft. above table to left of hood	0.013	3.38×10^{-10}	6.08×10^{-6}
In hood in draft from head dish	1.530	3.98×10^{-8}	7.16×10^{-4}
In flue of hood	2.060	5.36×10^{-8}	9.65×10^{-4}

TABLE 3.—*Concluded*

POSITION OF TIP	NET DRIFT OF LEAF DUE TO Tn *div./sec.*	CURIES OF Tn MEASURED	CURIES OF Tn PER CU.M.
Series 6			
Conditions during this run were the same as for the preceding series of measurements.			
On small table to right of hood	0.458	1.19×10^{-8}	2.14×10^{-4}
In hood to right of head dish	0.410	1.07×10^{-8}	1.93×10^{-4}
Over table to left of hood	0.427	1.11×10^{-8}	2.00×10^{-4}

Element	*Ion Pairs x 10^{-5}*
Radium Series:	
Radon	1.55
Radium A	1.77
Radium C′	2.20
Thorium Series:	
Thoron	1.78
Thorium A	1.92

Since at the end of three hours only 0.978 curie of radon and of each of its short-lived products remains in the electroscope chamber, the total ionization current at this time may be summed up by the expression:

$$0.978\left[(1.55 \times 10^5) + \frac{(1.77 \times 10^5)}{2} + \frac{(2.2 \times 10^5)}{2}\right] 3.72 \times 10^{10} \times$$

$$4.774 \times 10^{-10} = 6.15 \times 10^6 \text{ e. s. u.}$$

Adding 1 per cent. to this value, on account of the ionization by beta and gamma rays, and dividing by 0.978, the value 6.35×10^6 electrostatic units per curie is obtained.

A similar calculation for thoron, including thorium A as the only substance in equilibrium, yields the expression:

$$(1.78 + 1.92) \times 10^5 \times 3.72 \times 10^{10} \times 4.774 \times 10^{-10} = 6.59 \times 10^6 \text{ e. s. u. per curie}$$

Ion Pairs The number of ion pairs formed by an alpha particle from thorium A is not divided by 2 in this expression because the rapid rate of decay of this substance prevents complete deposition of its molecules or ions on the walls of the electroscope before decomposition.

The actual ionization current from a curie of radon at maximum activity in the electroscope has been determined by Randall (14) to be 78 per cent. of the value calculated above. This value was recently checked to 1 per cent. from the data of Table 2, using Randall's value of the electrostatic capacity.[1] In the case of thoron, it was assumed that the actual ionization current was 80 per cent. of the value

[1] A net drift of 1 division per second for an instrument whose electrostatic capacity is 14.7 cm. represents an ionization current of $0.0092 \times 14.7 = 0.135$ electrostatic unit. But as we have seen (Table 2), a net drift of 1 division per second is given by 27.5×10^{-9} curies of radon at the time of maximum activity. The ideal value for the ionization current produced by 1 curie of radon at the time of maximum is 6.21×10^6 electrostatic units, whence the ideal ionization current produced by 27.5×10^{-9} curies of radon will be $27.5 \times 10^{-9} \times 6.21 \times 10^6 = 0.171$ electrostatic unit. The measured current 0.135 electrostatic unit is nearly 79 per cent. of the ideal, while Randall found the ionization efficiency to be 78 per cent.

calculated above, largely because calculations show that an appreciable fraction of the thorium A particles reach the walls of the electroscope before decomposing. This assumption is thought to be good to ±10 per cent. On this basis the calibration constant of the instrument in terms of thoron is 26 x 10^{-9} curies per division per second. This constant, multiplied into the values found in the second column of Table 3, gives M, the number of curies of thoron apparently present in the electroscope during the measurement.

The calculation of the number of curies of thoron per cubic meter of the laboratory air is based on the following considerations. The half life period of thoron being 54.5 seconds, an appreciable fraction of the emanation entering the intake of the apparatus decays before reaching the electroscope chamber; and since the volume of the chamber is 2,840 c.c., a negligible fraction of the thoron entering will escape to the pump while the rate of flow is about 6 c.c. per second. Hence, if the steady state obtains,

Number of curies entering per second = number of curies decaying per second (1)

Let Q = number of curies entering the chamber per second

Then it follows from equation 1 that

$$Q = \lambda M \qquad (2)$$

where λ = transformation constant of thoron = 0.0128

M = curies of Tn measured (third column of Table 3)

$$Q = Q_o e^{-\lambda t} \qquad (3)$$

where Q_o = number of curies of Tn entering the intake per second

t = time necessary for the volume entering per second to pass from intake to chamber

$$= \frac{\text{volume of tubing and connections}}{\text{rate of flow}} = \frac{160}{\text{rate of flow}}$$

e = base of the natural logarithms

Combining equations 2 and 3, we have

$$Q_o = \frac{\lambda M}{e^{-\lambda t}} \qquad (4)$$

Then the amount of thoron per cubic meter of air is

$$\frac{Q_o \times 10^6}{\text{rate of flow}} = \left[\frac{0.0128 \times 10^6}{e^{-0.0128\,t}\ (\text{rate of flow in c.c. per second})}\right] M \qquad (5)$$

The rate of flow of air through the system during the measurements for Series 1 to 4, inclusive, was 5.75 c.c. per second, and for Series 5 and 6 it was 6 c.c. per second. Equation 5 for these cases thus reduces to

For Series 1 to 4, inc.:
Curies of Tn per cu. m. = (1.83 x 10^4) M

For Series 5 and 6:
Curies of Tn per cu. m. = (1.80 x 10^4) M

The results calculated in this manner and recorded in the fourth column of Table 3 are probably accurate to within 10 per cent. The electroscopic measurements are accurate to within 5 per cent., but other sources of uncertainty arise from the assumptions necessary in making the calculations.

J. I. H.
April, 1931

Discussion of Measurements on Radioactive Gases

The number of curies of thoron per cubic meter of air was in general about 1,000 times the number of curies of radon, and consequently more complete measurements were made on thoron than on radon. The results of Series 1 show that when the dishes are cold and circulation in the room is at a minimum, the thoron barely rises above the dishes before it decays, and that the air breathed by a person standing near the tables is practically free from this gas. On the other hand, when the solutions are being heated in the usual daily procedure, the thoron is much more widely distributed, and neither the draft produced by the fan of the hood nor any other means of circulation can prevent contamination of the air with this gas. The results of other series of measurements indicate the state of the atmosphere under a variety of conditions.

It is now of interest to calculate roughly the number of atomic disintegrations occurring per unit time in the lungs of a worker; this rate will be compared with the rate of emission of alpha particles from 10 micrograms of radium, an amount which, when deposited in the tissues of the body, is probably just within the limits of tolerance of the average person. (Radon is disregarded in this calculation.) A representative thoron content may be taken as 10^{-4} curies per cubic meter, or about 300 atoms per cubic centimeter. It follows that if by the process of breathing, about 3,000 c.c. of air in the lungs is maintained at the same emanation content as the laboratory air, the lungs will contain 9×10^5 atoms of thoron which, together with thorium A, will undergo $2 \times 9 \times 10^5 \times 0.0128 = 2.3 \times 10^4$ atomic disintegrations per second, or about 1,400,000 per minute, each disintegration being accompanied by the emission of an alpha particle. The corresponding number of disintegrations from 10 micrograms of radium is 66,000,000 per minute. From this comparison it appears that the dangers from thoron are slight, especially since the exposure is not continuous and the active deposits are short lived. There is, however, a possibility that the bombardment of the lung passages with alpha particles may eventually weaken the lungs or result in some unknown disorders.

Electroscopic Examination of Workers

During their term of employment the workers were examined for radioactivity at intervals of about a month. The tests were continued on two of the subjects for fully a year after they had stopped working in the refining laboratory.

The methods of detecting radioactivity in living persons described by Schlundt, Barker, and Flinn (17) were followed in testing the workers for radioactivity. During the first year the workers were examined by both the gamma ray method and the expired air method. As time went on, the tests were limited to the expired air, because it was found that by the gamma ray method, tests were deceiving unless special precautions were taken. Before a gamma ray test was made, the subject stayed out of the refining laboratory for a day. A thorough cleansing bath including a

hair shampoo was required, and a complete outfit of clothing not previously worn in the refining laboratory was insisted upon. Despite these precautions, irregularities in the gamma ray readings were obtained. The activities measured were generally close to the limit of detection by the instrument, 2 to 3 micrograms. Even these small positive values obtained now and then were finally ascribed to accidental contamination. When we substituted tested inactive garments for those from the wardrobe of the subject, the gamma ray tests became uniformly negative.

Nevertheless, the subjects when examined by the expired air method soon began to show radioactivity. The test for the presence of mesothorium by the expired air method is far more sensitive than the test for radium (17). The radioactive emanation of the thorium series, thoron, disintegrates about 6,000 times faster than radon, the radioactive gaseous product of the radium series. It is this fact which makes possible the detection of far smaller quantities of thoron than of radon in the expired air of radioactive persons. When a marked increase in discharge of the testing electroscope is produced by thoron in expired air, it must not be inferred that the person under examination should then, too, give a positive gamma ray test. Extremely small amounts of mesothorium 2, or thorium C″—the elements emitting gamma rays—doubtless are present in subjects expiring thoron, but the actual amount of these is too small to be detected by the gamma ray method of testing. A few millimicrograms—not micrograms—of mesothorium, measured as radium equivalent, will suffice to supply continuously detectable quantities of thoron.

The electroscopic tests for thoron in the expired air of the workers were not made immediately after they had been at work in the refining laboratory. Twelve to fifteen hours generally intervened. The laboratory in which the tests for activity of the workers were made was not in the same building with the refining laboratory. These tests were conducted in another building in a room reserved for the measurements of low grade radioactive materials. A Lind type of electroscope consisting of a 3-liter ionization chamber and interchangeable head was used.

As a general rule, the expired air tests were conducted in this way: The subject forced expired air through the chamber of the electroscope, volume 2,700 c.c., for three minutes. The air first passed through a drying tower of calcium chloride and cotton. The stopcocks of the chamber were then closed and readings of the drift of the charged leaf taken at once at intervals of 54.5 seconds, the half period of thoron. As an example, the net drifts taken over four successive half periods ran 17.5, 9, 4.6, and 2.2 divisions per second, values characteristic of thoron. The presence of radon in the expired air was rarely detected with certainty.

As time went on, the workers developed a distinct radioactivity. In one of the workers the presence of thoron was detected in the expired air after he had worked in the laboratory for only a few days. In the case of another worker two months passed by before thoron was detected in the

expired air. The quantity of thoron, although fluctuating, gradually increased in all the workers, with length of service.

Some tests on individual workers will now be given. The expired air from one of the workers produced a net drift of 22 divisions during the first half period of 54.5 seconds. The test was made two days after he stopped working in the laboratory. After three months he was tested again with the same instrument. The net drift had dropped from 22 to 1.9 divisions.

Another worker (H. S. in Table 4) had developed an activity of 19 divisions net drift in 54.5 seconds at the time he stopped working in the refining laboratory. A year later the test gave a net drift of only 2.2 divisions in 54.5 seconds. We are thus inclined to say that the activity acquired during employment in the refining laboratory does not become fixed in the body.

Still another worker in a crystallizing laboratory where mesothorium bearing chlorides are purified and fractionated was tested by both the gamma ray and the expired air methods. Both tests were absolutely negative. This subject is 63 years old, and has worked in a refining laboratory regularly for a period of three years. During this period he has "stepped up" the chloride crystals and has thus handled about 2,200 mg. of mesothorium expressed as radium equivalent.

During the summer of 1929, Mr. H. A. Mangan (18) made a series of expired air tests on one of the workers in the refining laboratory who was at work daily during the period over which the measurements extended. This worker admitted that he had not exercised proper care in handling a sample of radioactive material. The net drift observed soon after was 17.5 divisions during the initial half value period of 54.5 seconds. The worker was then requested to exercise greater care in laboratory manipulations. Three days later he was tested again and found to be only half as active, the net drift being 9.7 divisions. Three weeks later, with continued care, the drift had dropped to 2.6 divisions.

Finally, with a view to getting better quantitative data on the thoron content of expired air, two of the workers were tested one hour after they had worked for four hours in the refining laboratory. At the time of the tests about 300 mg. of mesothorium were in process. The method of testing was modified by taking readings while the subject forced air continuously through the chamber. A net drift of 0.9 division per second was the maximum rate observed. The constant of the instrument used was 15.3×10^{-9}. The actual number of atoms of radon disintegrating per second for a drift of 1 division per second under conditions of the calibration is given by $15.3 \times 10^{-9} \times 3.7 \times 10^{10} = 566$. A net drift of 0.9 division per second would represent about 510 atoms of radon decomposing per second. If it is assumed as a first approximation that the same number of atoms of thoron disintegrating per second in the chamber produce a net drift of 0.9 division per second, this number also represents the concentration of thoron in the air of the lungs, the capacity of the chamber and the lungs being about the same, 3,000 c.c. each.

TABLE 4.—BLOOD COUNTS OF THREE WORKERS IN MESOTHORIUM LABORATORY

DATE	HEMOGLOBIN	ERYTHROCYTES	LEUKOCYTES	DIFFERENTIAL LEUKOCYTE COUNT				
				Polymorphonuclears	Eosinophils	Basophils	Lymphocytes	Large Mononuclears
	%	*millions per c. mm.*	*per c. mm.*	%	%	%	%	%
			Subject A. H.					
9/ 7/28	95	4.560	4,400	55.0	1.5	0.5	38.0	5.0
10/ 2/28	70–80	4.800	4,500	48.0	1.0	0.0	45.0	6.0
11/ 8/28	95	5.220	4,224	57.0	1.0	0.0	40.0	2.0
12/ 5/28	93	4.200	4,224	59.0	1.0	0.0	37.0	3.0
1/ 7/29	93–95	5.120	6,240	60.0	0.5	0.5	37.0	2.0
2/ 8/29	100	4.960	5,760	61.0	1.5	0.5	36.0	1.0
			Subject W. C. McG.					
10/19/27	85	4.264	4,896	57.5	3.5	1.0	29.3	8.7
11/ 2/27	82	4.800	5,920	68.5	1.0	0.7	26.0	3.8
11/17/27	83	4.472	6,240	70.7	0.7	0.0	22.0	6.6
12/ 1/27	..	4.512	4,410	73.5	2.5	0.0	19.0	5.0
12/15/27	83	4.776	5,340	66.5	3.5	0.0	24.0	6.0
12/29/27	82	4.376	6,590	43.0	1.3	0.7	47.0	8.0
1/12/28	82	4.320	5,000	60.0	2.0	0.0	32.0	6.0
1/26/28	83	5.096	3,008	57.0	2.0	1.0	33.0	7.0
2/ 9/28	83	4.032	5,664	64.3	1.3	0.0	27.0	7.4
2/23/28	80	4.160	7,136	69.5	3.0	1.0	21.5	5.0
3/ 8/28	83	4.776	5,884	75.0	1.0	0.0	21.0	3.0
3/22/28	80	4.576	5,184	72.0	2.0	0.5	20.5	5.0
4/10/28	85	4.088	4,670	61.5	2.0	0.0	32.5	4.0
4/19/28	83	4.720	4,190	59.0	5.0	0.0	30.0	6.0
5/ 3/28	81	4.888	5,540	66.0	3.0	0.0	26.0	5.0
6/22/28	93	4.320	8,060	63.0	3.0	0.0	27.0	7.0
10/28/30	93	4.870	6,600	55.0	3.0	0.0	42.0	0.0
			Subject H. S.					
10/19/27	86	4.553	7,096	49.0	2.0	0.0	45.0	4.0
11/ 2/27	83	4.488	6,464	51.0	0.8	1.0	40.2	7.0
11/17/27	83	4.696	8,256	48.0	0.0	0.0	43.0	9.0
12/ 1/27	82	4.120	6,270	47.7	0.3	0.0	48.0	4.0
12/15/27	86	4.784	8,000	46.0	2.0	0.0	46.0	6.0
12/29/27	85	4.704	8,540	54.0	4.0	0.7	34.0	7.3
1/12/28	87	4.296	8,384	54.0	2.0	0.0	37.0	7.0
1/26/28	83	5.296	6,050	47.0	4.0	1.0	37.0	11.0
2/ 9/28	83	4.450	6,976	41.0	3.0	0.0	45.0	11.0
2/23/28	84	4.192	8,480	45.0	0.7	0.7	48.0	5.6
3/ 8/28	86	4.104	6,340	48.0	2.0	0.0	42.0	8.0

J. I. H.
April, 1931

TABLE 4.—*Concluded*

DATE	HEMOGLOBIN	ERYTHROCYTES	LEUKOCYTES	DIFFERENTIAL LEUKOCYTE COUNT				
				Polymorphonuclears	Eosinophils	Basophils	Lymphocytes	Large Mononuclears
	%	*millions per c. mm.*	*per c. mm.*	%	%	%	%	%
			Subject H. S.					
3/23/28	85	4.625	5,760	48.0	1.0	0.0	49.0	2.0
4/20/28	87	4.616	9,376	47.0	1.0	0.0	46.0	6.0
5/ 7/28	90	4.984	7,390	60.0	1.3	0.0	33.0	5.7
5/28/28	85	4.800	6,370	59.0	1.0	1.0	34.0	5.0
6/22/28	92	4.000	7,300	63.0	1.0	0.0	32.0	4.0
7/ 7/28	85	3.480	5,696	55.0	2.0	0.0	40.0	3.0
9/ 7/28	87	4.350	5,900	56.0	3.0	0.0	36.0	4.0
10/ 3/28	85	4.590	7,460	60.0	1.0	0.0	34.0	5.0
10/27/28	97	4.940	6,144	48.0	2.0	1.0	46.0	2.0
12/10/28	85	4.282	5,760	55.0	0.3	0.7	40.0	4.0

Earlier in this paper (p. 127) it was deduced that the air breathed by the workers in the refining laboratory carries a concentration of thoron which produces 11,500 atomic disintegrations per second, a ratio fully twenty times greater than the thoron content exhaled by the most active worker.[2]

Cytology of Workers

From this study of the cytology of the young men exposed to repeated daily doses of radiation from mesothorium and radium it was hoped to ascertain whether or not disturbance in hematogenesis would be demonstrated. Furthermore, would not such examinations be of value as a routine safety measure in places where radioactive material is handled?

Blood counts were made upon the workers in the laboratory at intervals of two weeks for two of them and at intervals of one month for the third, during the period of employment. Since the termination of the work two subjects have had further examinations.

The usual methods of blood examination were employed, especial care being taken to have the conditions as uniform as possible. Hemoglobin was recorded, and red, white, and differential counts were made before the subjects began work in the mesothorium laboratory. Blood was collected sometime between 2 and 5 o'clock in the afternoon in the same standardized pipettes by one technician. The blood was diluted 1 to 20 with 2 per cent. acetic acid for the white count, and 1 to 200 with a 0.9 per cent. saline solution for the red count. A full count of 100 squares was made in each count. All hemo-

[2] A more extended electroscopic examination of the workers is in progress.

globin determinations were made with the same Dare hemoglobinometer. The differential count was made from slides stained with Wright's stain, 300 or more cells being classified. These slides were also examined for the appearance of abnormal red cells, the reticulated reds, or abnormalities in shape, size, or staining. The normal value for hemoglobin is 100 per cent.; for erythrocytes from 4,500,000 to 5,500,000 per cubic millimeter; for leukocytes from 6,000 to 8,000; for polymorphonuclear leukocytes 63 to 70 per cent.; eosinophils 2 per cent.; basophils 0.5 per cent.; lymphocytes 20 to 30 per cent.; large mononuclear leukocytes 10 per cent. The results for three of the workers are given in Table 4.

On examining the table, it is seen that the initial, and presumably normal, red count and hemoglobin value of W. C. McG. and of H. S. and the polymorphonuclear leukocyte percentages of H. S. were below the accepted standard for healthy young men. The differences were not large, and there is no marked variation from these values during the period of the experiment except in the case of H. S. He definitely increased his red count during the summer months when he was able to get more out-of-door exercise. This improvement has continued. W. C. McG. had one abnormal white count (3/8/28) shortly before an attack of influenza. Except for this illness the health of the workers was quite normal throughout this period.

Since the blood of these subjects shows no abnormality, it is concluded that the exposure to the amount of radioactive material found in this laboratory has produced no injury to the hematopoietic organs, at least so far as can be measured by the procedure used.

Summary

In the laboratory used for the refining of radium and mesothorium the intensity of the radiations from all sources has been reduced to a practical minimum. The ways and means of attaining these favorable circumstances have been described. Only two radiations remain which may be regarded as potentially harmful: (1) the gamma rays not removed by the shields and other screening devices, and (2) the alpha rays from emanations present in the air breathed by the worker.

The effects of the much reduced intensity of gamma radiations have never become apparent. The consequences to the body glands of exposure to this intensity over a period of years have not been investigated.

The amounts of radon and thoron in the laboratory air were measured quantitatively, the latter by an original application of a continuous flow method. The thoron content was of the order of 10^3 times greater than the radon content, which in turn was 10^3 to 10^6 times greater than the radon content of the earth's atmosphere. It was calculated that the number of atomic disintegrations occurring in the lungs of a worker was approximately 2 per cent. of the number occurring in the body of a person carrying an amount of radium just within the limits of tolerance.

For protecting workers the electroscopic examinations give a timely

warning of danger, far more sensitive than any other method.

Since the blood of the workers showed no abnormality, it is concluded that the exposures in the refining laboratory have produced no injury to the hematopoietic organs, at least so far as can be measured by the procedure used.

None of the workers (five in all) has experienced any debilitating effects. Indeed, none were anticipated, for the refining process had been carried out in the past in this laboratory, at a time when the precautions here described were unheard of, without any harmful results to the workers, even though they were observed over a period of ten years after ceasing work. It may be concluded with certainty that exposure to the radiations may be reduced to such an extent that the effects over a period of two or three years are negligible.

We owe thanks to Dr. G. F. Breckenridge for his generous co-operation in this investigation; also to Claude E. Welch and Henry Skinner, graduate students, for assistance with various portions of the work. The radioactive materials used were supplied by the Welsbach Company, through the courtesy of Dr. H. S. Miner.

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   (Av. = 8.3 x 10^{-11} curies per cubic meter.)
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    (Rn mean content 10 cm. above surface = 1.73 x 10^{-20} curies per c.c. 11.5 m. above surface = 1.42 x 10^{-20} curies per c.c.)
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THE REDUCTION OF MINE AIR TEMPERATURES*

T. Bedford, Ph.D., and C. G. Warner, B.Sc.

From the Industrial Health Research Board, London

Methods of Improving Atmospheric Conditions

With the development of mining at great depths, the problem of securing comfortable working conditions is one of increasing importance. As mines increase in depth and extent, it becomes more and more necessary to compensate for the rise in air temperature consequent on increased strata temperatures and on oxidation.

Possible methods of obtaining better atmospheric conditions are: (1) by increasing the air movement, either generally or locally; and (2) by the application of some general or local method of air cooling.

Hay and Clive (1) have emphasized the view that the best and most economic method of keeping the temperature of the air below the strata temperature is by maintaining large airways, a judicious number of splits, and a large volume of air circulating. By this means the twofold effect is secured of increasing the air velocity and reducing the temperature. Rees (2) (3) has shown that where the quantity of air passing is small, there is a considerable rise in temperature, through the conduction from the walls, during its brief passage down the shaft. On the other hand, where the volume of air is large, the rise in temperature from this cause is negligible even in shafts nearly 3,000 feet deep. Similarly, along the air roads, the rise in temperature is less as the volume of air passing is greater. Ranson (4), in discussing the ventilation of mines on the Witwatersrand, has also drawn attention to the cooling effect of large volumes of air.

In older pits it is often difficult to circulate large volumes of air, and in such cases, considerable improvement can often be obtained by the local use of small auxiliary ventilating units. Hancock (5) gives valuable data concerning the use of such units. In order to supplement the ventilation of one district in a certain colliery he installed a centrifugal fan 2 feet, 3 inches in diameter. The air velocity at the coal face was increased from 16 to 65 feet per minute, the dry bulb temperature was reduced from 75° to 71°, and the wet bulb from 74.5° to 69.5°.

Discussing possible means of improving conditions at the Village Deep Mine on the Witwatersrand, Mavrogordato and Pirow (6) conclude that local air movement on the jet or douche principle appears to be the most helpful method.

Different methods of securing a general reduction in air temperature, other than by increasing the circulation, have been attempted with varying

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measures of success. Probably the best known example is the use of refrigeration at the Morro Velho Mine in Brazil (7). The outside air at a temperature of 72° (wet bulb) is cooled to 43.2° by the large refrigerating plant situated on the surface. At the working face the wet bulb temperature is lowered from 89° to 80°, but the effect on the dry bulb temperature is much less marked. The air takes up so much heat from the surfaces with which it comes in contact that the dry bulb temperature at the working face is only 2° or 3° lower than before.

Other methods of cooling the intake air include the use of water sprays, or passing the air over blocks of ice or over cold water radiators.

While it may be possible by such means to chill the air below its dew point, and thus secure some reduction in the wet bulb temperature, these methods of cooling the air at the surface, or in the main intake, do not seem likely to cause a lowering of the dry bulb temperature at the working face. Owing to its low specific heat, the air is very rapidly rewarmed by contact with the rock surface, and in traveling a considerable distance to the face it has time to regain equilibrium with the zone of rock surrounding the airway.

Local refrigeration was attempted by Hancock (8). The refrigerator, of the carbon dioxide compressor type, was installed in the intake airway of the district under investigation. No positive result was achieved, however, and it was said that the machine either was too small for its work or, alternatively, was erected too far from the coal face.

Local cooling by means of ice has been used at the Village Deep Mine (9). Ice was placed on trays in the delivery ends of the 15-inch ventilation pipes. The temperature of the air delivered from the pipes was reduced by 6°F. The temperature reduction at the face depended on the proximity of the ventilating column. With the delivery end of the column 15 feet away, the temperature at the face was reduced by from 2° to 3°.

Experiment in Local Air Conditioning by Means of Artificial Humidification

Certain observations on the working capacity of coal miners in relation to atmospheric conditions, made on behalf of the Industrial Health Research Board, suggested that in a hot, dry mine it might be possible to improve the working conditions by means of artificial humidification. In order that this conclusion might be put to a practical test, we carried out an experiment in air conditioning by this method at a certain colliery.

The place selected for the work was a small district comprising a short length of coal face of about 170 yards, worked on the advancing longwall system. The distance of the coal face from the bottom of the downcast shaft is about $1\frac{1}{2}$ miles, and the amount of cover is 637 yards.

From preliminary observations it was found that the volume of air passing along the level leading to the coal face was approximately 12,500 cubic feet per minute, at temperatures of about 75° dry bulb and 65° wet bulb. It was calculated that to saturate this volume of air at the wet bulb temperature of 65° it would be necessary to evaporate about 12 gallons of water an hour.

The humidification was effected by means of a range of five Andrew humidifying heads placed 2 yards apart, each head being capable of atomizing 3 gallons of water an hour. Compressed air aspirates water into the humidifying head and discharges it in an atomized condition. The air and water supplies to each head can be independently controlled, and the heads are adjustable so that the spray can be discharged in any required direction. We adjusted them so that across the whole section of the airway there was a screen of finely atomized water, and in this way we were able to increase the saturation of the air from about 45 per cent. to 80 per cent. The water used by the atomizers was brought specially from the pit bottom.

It was decided to install the humidifiers near the point where the air reached the coal face, but at the beginning of our observations it was found inconvenient to fix the apparatus in the desired position for a few days. Some preliminary observations were therefore made with the humidifiers placed further back in the air road, about 120 yards away from the coal face. Later, the apparatus was moved up to within about 10 yards of the coal face and further temperature observations were made. Figures 1 and 2 show the average conditions observed in the two series of observations.

From Figure 1 it will be seen that in the earlier observations humidification lowered the dry bulb temperature by 7°—from 74.4° to 67.4°—but by the time the coal face was reached the air had been warmed so that it was only 2.1° cooler than with normal ventilation. Further along the face the dry bulb temperatures shown by the two curves are practically the same. The curves of water content, which is expressed as grains of water vapor per pound of dry air, show that the air was slightly more moist to begin with on days when the atomizers were used. There was a sudden rise in moisture content at the point of humidification, but afterward the rate at which water was picked up was less than with normal conditions, so that along the latter half of the coal face the moisture content of the air was nearly the same in the two sets of observations. The

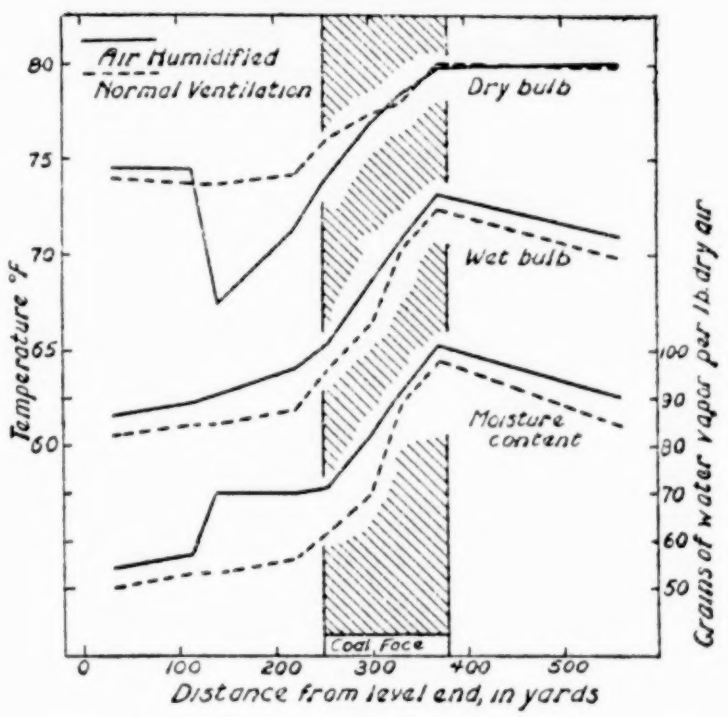

FIG. 1.—Effect of humidification, with atomizers 120 yards from coal face.

middle pair of curves shows that the wet bulb temperature started rather higher on the days when the air was conditioned, but the curves run practically parallel to each other, and the humidification does not appear to have caused any sensible rise.

The average conditions observed when the atomizers were situated close to the coal face are shown in Figure 2. When the atomizers were working, the dry bulb temperature in their vicinity was reduced by 9°. Where the air entered on to the coal face it was 7.8°

less than under normal conditions, but after passing along 35 yards of face this difference had been reduced to 1.9°, and after another 44 yards had been traversed the difference was only 1.1°. Further along the face the cooling effect vanished. The curve of moisture content shows a marked rise toward the return end of the coal face. This is not due to the effect of the air conditioning, but to the evaporation

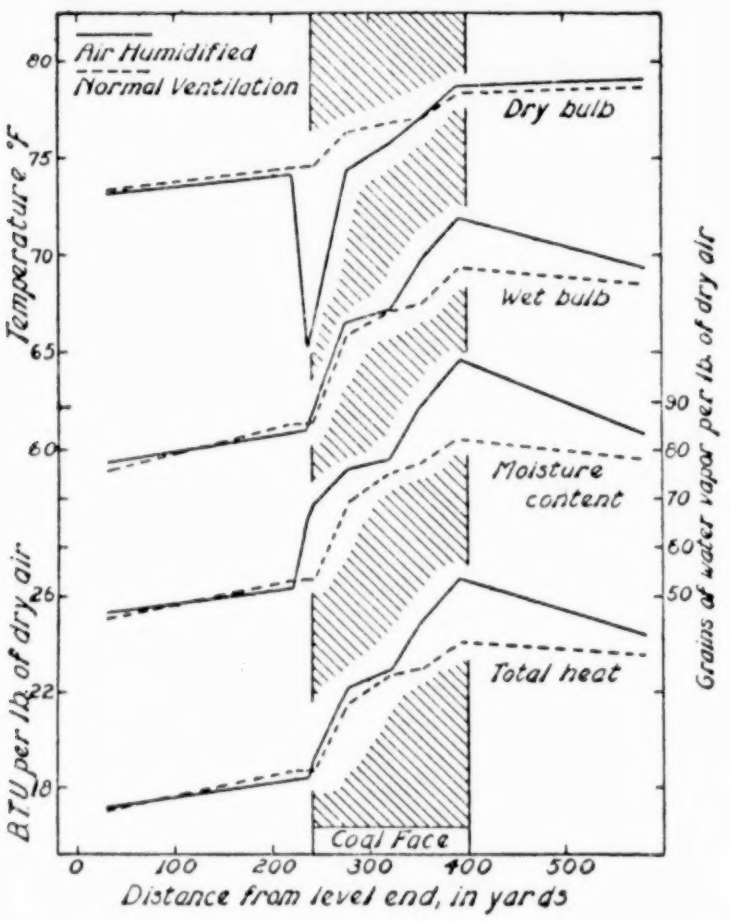

FIG. 2.—Effect of humidification, with atomizers close to coal face.

of water which, for some days, dripped from the roof at that end of the face. The wet bulb temperatures shown by the two curves are almost identical until the second half of the coal face is reached, and there the effect of seepage from the roof is shown.

A comparison of Figure 2 with Figure 1 shows that, after conditioning, the air warmed up much more quickly when the atomizers were close to the coal face. This is due, of course, to the more rapid emission of heat from the newly exposed surfaces. In the lowest pair of curves in Figure 2 is shown the total heat content of the air, expressed as British thermal units per pound of dry air. This figure represents the amount of heat which it would be necessary to remove from a mixture of dry air and water vapor in order to cool it, under constant barometric pressure, to 32°F., and to condense out all the water vapor into liquid water at 32°. The values have been calculated according to the equation given by J. S. Jones (10). The curves show a much more rapid gain of heat along the coal face than in the intake approaching the face.

CONCLUSIONS

The observations on air conditioning show that where the rate of heat emission was low, the cooling influence of the humidification was felt over a reasonable distance. When the atomizers were situated 120 yards from the coal face the air temperature 85 yards beyond them was still 3° lower than with normal ventilation. However, when the rate of heat emission was high, as along the coal face, the cooling effect of conditioning was soon lost. For instance, Figure 2 shows that while the conditioned air reached the coal face 7.8° cooler than under normal conditions, by the time it had traveled along 35 yards of face this difference was reduced to 1.9°. The experiment was carried out under favorable conditions, in a district with good ventilation. With a more sluggish ventilation the rise in temperature after conditioning would probably have been much more rapid.

Our results lead to the conclusion

that air conditioning by artificial humidification is not likely to be of value for general application in hot and dry mines. The method might, however, be used in such mines as a palliative measure in certain isolated circumstances, always provided that the humidification could be done quite close to the working position. The real solution of the high temperature problem appears to be the provision of large volumes of rapidly moving air.

Summary

Various methods of obtaining a cooler atmosphere in mines have been mentioned, and an experiment in local air conditioning by means of artificial humidification has been described.

The air conditioning was tried on a coal face 170 yards in length, and the effects of humidification were observed when the apparatus was placed (*a*) 120 yards away from the face, and (*b*) close to the face. In the former case the conditioning reduced the air temperature by 7°, but the temperature rose quickly, and by the time the coal face was reached it was only 2.1° lower than under normal conditions. With the apparatus working close to the coal face the air reached the face 7.8° cooler than under normal conditions, but after traversing 35 yards of face the cooling effect was reduced to 1.9°, and further along the face the effect was barely noticeable.

The conditioning caused no sensible rise in the wet bulb temperature.

It is concluded that air conditioning by this method is not likely to be of value for general application, but that it might be used as a palliative measure in certain circumstances.

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A COLORIMETRIC METHOD FOR THE DETECTION AND ESTIMATION OF SMALL AMOUNTS OF LEAD*

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HAVING use for a method for the detection and estimation of small quantities of lead (less than 0.2 mg.) in the presence of inorganic substances in water samples taken in connection with studies on lead in air, the authors were led to investigate the standard methods for the determination of this element as described in various textbooks. Very unsatisfactory results were obtained with most methods, and those that gave fairly accurate results were so tedious and required so much technic that for routine use they were prohibitive. With the foregoing results at hand, the method here described was finally used. It is based on a modification of the methods discussed by Fairhall (1), while the exact procedure is a substantial modification of the work of Kehoe, Edgar, Thamann, and Sanders (2). The method is accurate to the extent of 0.005 mg. of lead, provided samples taken are very small (0.2 mg. or less), and the technic is not so complicated as to make its use limited to analysts with a high degree of manipulative skill. Moreover, it allows the reporting of results within twenty-four hours after receipt of the sample in the laboratory.

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PROCEDURE

If the sample under examination is in solid form, it should be pulverized to pass through a 100-mesh sieve, and a representative sample of this powder should be taken and placed in 50 c.c. of distilled water. The sample should be of such size as to contain not more than 0.2 mg. of lead. In the case of a lead bearing liquid or a suspension of lead bearing material, an aliquot portion containing approximately 0.2 mg. of lead, or less, should be used. Add to the sample,[1] prepared as above, 25 c.c. of nitric acid (1:1), evaporate to between 2 and 4 c.c., cool, and make up to 80 c.c. with distilled water. Add 4 drops of phenolphthalein solution (0.5 per cent. in 1 per cent. sodium hydroxide) and neutralize with 25 per cent. sodium hydroxide solution, adding an excess of 5 drops. Acidify with 5 per cent. acetic acid until the pink color just disappears, and add 2 c.c. in excess. Bring to the boiling point and precipitate the lead as chromate by adding 1 c.c. of 1 per cent. potassium chromate solution. Place on a steam bath for one hour and allow to stand in a warm place (about 20°C.) overnight. Heat just below boiling

[1] All lead bearing samples should be soluble in hot concentrated nitric acid.

TABLE 1.—EXPERIMENTAL RESULTS

EXPERIMENT NO.	LEAD		FOREIGN SUBSTANCE	
	Amount Used	Amount Found	Name	Amount Used
	mg.	*mg.*		*mg.*
1	0.000	0.000	Aluminium	0.100
2	.100	.098	Aluminium	.100
3	.200	.208	Aluminium	.100
4	.000	.000	Antimony	.100
5	.100	.094	Antimony	.100
6	.200	.208	Antimony	.100
7	.000	.000	Arsenic	.100
8	.100	.098	Arsenic	.100
9	.200	.208	Arsenic	.100
10	.000	.000	Barium	.100
11	.100	.102	Barium	.100
12	.200	.206	Barium	.100
13	.000	.000	Bismuth	.100
14	.100	.104	Bismuth	.100
15	.200	.214	Bismuth	.100
16	.000	.000	Cadmium	.100
17	.100	.100	Cadmium	.100
18	.200	.204	Cadmium	.100
19	.000	.000	Calcium	.100
20	.100	.098	Calcium	.100
21	.200	.194	Calcium	.100
22	.000	.000	Cobalt	.100
23	.100	.096	Cobalt	.100
24	.200	.200	Cobalt	.100
25	.000	.000	Copper	.100
26	.100	.090	Copper	.100
27	.200	.093	Copper	.100
28	.000	.000	Iron	.100
29	.100	.094	Iron	.100
30	.200	.098	Iron	.100
31	.000	.000	Magnesium	.100
32	.100	.104	Magnesium	.100
33	.200	.206	Magnesium	.100
34	.000	.000	Manganese	.100
35	.100	.100	Manganese	.100
36	.200	.204	Manganese	.100
37	.000	.000	Mercury	.100
38	.100	.090	Mercury	.100
39	.200	.200	Mercury	.100
40	.000	.000	Nickel	.100
41	.100	.102	Nickel	.100
42	.200	.212	Nickel	.100

TABLE 1.—*Concluded*

EXPERIMENT NO.	LEAD		FOREIGN SUBSTANCE	
	Amount Used	Amount Found	Name	Amount Used
	mg.	*mg.*		*mg.*
43	0.000	.000	Silver	0.100
44	.100	0.092	Silver	.100
45	.200	.092	Silver	.100
46	.000	.000	Strontium	.100
47	.100	.100	Strontium	.100
48	.200	.204	Strontium	.100
49	.000	.000	Tin	.100
50	.100	.094	Tin	.100
51	.200	.196	Tin	.100
52	.000	.000	Zinc	.100
53	.100	.098	Zinc	.100
54	.200	.206	Zinc	.100
55	.005	.006	None	....
56	.100	.108	None	....
57	.150	.150	None	....
58	.200	.220	None	....
59	.000	.000	All above	.100 of each
60	.100	.100	All above	.100 of each
61	.200	.224	All above	.100 of each

for fifteen to twenty minutes and filter hot through a filter (no. 42 Whatman —11 cm.) which has been washed down with hot water. Rinse the beaker thoroughly on to the filter paper with hot water, washing the precipitate well with hot water in order to remove all traces of soluble chromates. Place 15 c.c. of hydrochloric acid (1:2) in the beaker which was used for precipitation, and rinse the sides of the beaker well with the acid. Place the funnel containing the filter and precipitate over a 200-c.c. volumetric flask and carefully pour the hydrochloric acid which is in the beaker over the entire surface of the filter paper. Rinse the beaker on to the filter paper and then

wash the filter thoroughly, using cold distilled water for both operations.

To the solution in the volumetric flask add 2 c.c. of s-diphenyl carbazide solution (1 per cent. in glacial acetic acid) and make up to the mark with distilled water. Shake well and, by means of a colorimeter, estimate the amount of lead in the sample by comparing the intensity of the pink color (3) against a known standard.

To make a lead standard to be used for matching against the unknown sample, dissolve 0.142 gm. of potassium dichromate ($K_2Cr_2O_7$) in distilled water and make up to 1 liter; 1 c.c. of this solution is equivalent to 0.2 mg. of lead. Take 5 c.c. of this solution, add 2 c.c. of s-diphenyl carbazide, and make to 1 liter; 1 c.c. of this solution is equivalent to 0.001 mg. of lead.

Experimental

Fearing that the presence of certain other basic constituents might seriously interfere with the procedure here given, the authors undertook a series of experiments to test this point with samples containing known amounts of lead and known amounts of impurities. There was no interference from any of the substances used. The results in Table 1 are self-explanatory.

Discussion

All apparatus should be washed, before using, with hot 10 per cent. nitric acid, and then with distilled water, in order to insure freedom from lead. A blank test should be run to determine the purity of the reagents.

It was determined that if the color standard was made up to the strength outlined above, the sharpest color change was noted. A Campbell-Hurley modification of the Kennicott-Sargent colorimeter (4) was used.

It is advisable to make up the s-diphenyl carbazide reagent and the color standard solution (that is, the potassium dichromate-s-diphenyl carbazide solution) fresh each day. The stock solution of potassium dichromate may be kept indefinitely.

This method was originally developed as a means of determining, with an accuracy of 10 per cent., the lead content of air samples, which were taken with a Greenburg-Smith impinger (5). It should be noted from the experimental results, however, that owing to the noninterference of other metallic as well as alkali-earth constituents when present in amounts of 0.1 mg. or less, the method has wide application. Control of these ingredients can be kept, in nearly every case, by the selection of a suitable aliquot portion of the original sample. Excessive amounts of phosphate should interfere with the method.

Summary

1. A rapid and rather exact method has been developed for the estimation of lead in amounts under 0.2 mg.

2. A great many metals and alkali-earths do not interfere with the method when the amounts are kept below 0.1 mg.

3. This method should, therefore, have a certain scope of application, not only in industrial health work but also in other fields demanding a rapid chemical microanalytic method for the determination of lead.

J. I. H.
April, 1931

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BOOK REVIEW

CASE STUDIES OF UNEMPLOYMENT. 150 Preventable Misfortunes. Research Study No. XII, Industrial Research Department, Wharton School of Finance and Commerce, University of Pennsylvania. Compiled by the *Unemployment Committee of the National Federation of Settlements*. Cloth. Pp. 418 with index. Philadelphia: University of Pennsylvania Press, 1931.

This book introduces to us individual and family situations in which from the fact of broken employment we trace progressive economic degradation leading often to disorganized family relations and demoralized individuality. The poignancy of these stories stirs at least an emotional protest against an economic system which fails to prevent such misfortunes. The means by which these misfortunes are preventable are not clear under a system of competitive individualism, the principles of which most, if not all, of us accept in practice.

An expansion of these case studies to trace not only consequences but causes of broken employment would add substance to our emotional protest. Such studies honestly pursued would lead us from the fact of broken employment back through the employment selection of the more capable workers; through the mazes of finance concerned with ownership and operation, and distribution and sale; back to the motives of all of us who buy de luxe automobiles or shop in the "5-and-10." Such studies should open our eyes to candid appraisal of social justice at every point where the insatiable human desire to get more and more for less and less exerts its relentless pressure upon our economic system. Such unequivocal pursuit of the case studies of this book might for many of us transform an emotional protest against an impersonal system into a rational and practical sense of personal responsibility in the misfortune of the less fortunate individuals of our competitive system.—*Harold W. Stevens.*

BOOKS RECEIVED

Books received are acknowledged in this column, and such acknowledgment must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interest of our readers and as space permits.

CHININ IN DER ALLGEMEINPRAXIS. By *Fritz Johannessohn*, M.D., Mannheim, Germany. Paper. Pp. 232 with index and bibliography. Amsterdam: Bureau tot Bevordering van het Kinine-Gebruik, 1930.

THE PREVENTION OF DISEASE IN THE COMMUNITY. By *Curtis M. Hilliard*, Professor of Biology and Health, Simmons College, Boston, Mass.; Health Supervisor, Wellesley and Weston, Mass. Cloth. Pp. viii, 193 with index. New York: McGraw-Hill Book Co., Inc., 1931.

DISCOVERING OURSELVES. A VIEW OF THE HUMAN MIND AND HOW IT WORKS. By *Edward A. Strecker*, A.M., M.D., and *Kenneth E. Appel*, Ph.D., M.D. Cloth. Pp. xiii, 306. New York: The Macmillan Co., 1931.

THE CRIMINAL, THE JUDGE, AND THE PUBLIC. By *Franz Alexander*, M.D., Visiting Professor of Psychoanalysis at the University of Chicago, and *Hugo Staub*, Attorney at Law, Berlin. Translated from the German by *Gregory Zilboorg*, M.D., Bloomingdale Hospital, White Plains, N. Y. Cloth. Pp. xx, 238 with index. New York: The Macmillan Co., 1931.

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April, 1931